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Author(s):	Schultz, Pete Aberle, Derek Jacob Tomkins, Christopher David
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Bayes Inference Engine (BIE) Test Plan: TiltConeBeamCombo

Pete Schultz – New Mexico Consortium

Derek Aberle – LANL

Chris Tomkins – LANL

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Bayes Inference Engine TEST PLAN: BTP070

Glyphs Tested: TiltConeBeamCombo

Test Results: BTR070

1. Introduction

The Bayes Inference Engine (BIE) is a general software tool intended to be used primarily in the analysis of radiographic data for density. An analysis is set up in the BIE by representing the problem as a collection of modules called glyphs. All glyphs to be used in creating the forward model of the experiment will be tested separately for a range of inputs.

The testing of the adjoint code is performed in a separate document.

2. Operation of the glyphs

The glyph is designed to calculate the path integral from a point source to a pixelated detector through an axi-symmetric object defined by a pixelated density grid. The user sets various parameters via a dialog box.

Glyph Inputs/Outputs:
There is a single input and output node for this glyph.
Input: a Uniform2DGrid
Output: a Uniform2Dgrid

User supplied parameters:
  Source to Object Distance (in cm.).
  Object to Detector Plane Distance (in cm.).
  Tilt Angle of Object Axis (in degrees) - positive values mean that the upper portion of the object is tilted towards the source.
  Left-Right Blend Distance (in cm.) – This is always set to 0.0.
  Number of Iterations for Inverse – Not Tested here, inverse is not used.
  Input Plane:

Starting Position	X(cm)	Y(cm)
Size	X(cm)	Y(cm)
Number Pixels	Nx	Ny

  Output Plane:

Starting Position	X(cm)	Y(cm)
Size	X(cm)	Y(cm)
Number Pixels	Nx	Ny

LIMITS OF USE:

   1. Accuracy: This glyph may exceed an accuracy limit of 0.4% (RMS error / Max Value) if the tilt angle exceeds +/-80 degrees.

   2. Runtime: This glyph shows a significant increase in runtime for tilt angles exceeding +/-80 degrees.

   3. Tilt angle limits: This glyph cannot be used if the magnitude of the tilt angle is great enough that all rays from the source that enter the input region enter from the top or the bottom. Additionally, memory requirements increase as the magnitude of the tilt angle increases, so that the glyph cannot be used if the tilt angle has high enough magnitude that the memory limits are exceeded.

   4. Low conjugate limits: If the source-object distance is not sufficiently large relative to the size of the input grid, the glyph may exceed memory limits, or require substantially longer runtimes.

   5. High conjugate limits: For near-zero tilt angles and long first conjugates, the error in this glyph exceeds testing limits for cylinder test problems. This is because rays that pass near the cylinder's top and bottom surfaces are almost parallel to these surfaces, causing issues with partial pixels. At a tilt angle of zero degrees the error may exceed 0.4% for conjugates of 200cm or greater.

3. Functionality to be Tested

The glyphs will be tested to ensure that they carry out the specified operations. These tests will be carried out over the normal range of operation. The test objects will be uniform-density cylinders and spheres, and comparison will be made with exact analytical results.

Pass/Fail Criteria: Each test consists of several subtests, and each subtest contains consists of one or more runs with a specified set of input parameters. The imaged object is either a uniform sphere or uniform cylinder with specified dimensions. Because the imaged object is either a sphere or cylinder, the exact analytical solution for any ray can be determined. For each run, the computed integrals are compared to the exact analytical solution obtained by raytracing to the center of each output grid pixel. A normalized RMS error is computed by taking the sum of squares of the errors over all pixels in the output grid, dividing it by the number of pixels for which the exact analytical solution is nonzero, and then dividing by the maximum value of the exact analytical solution. That is,

$$NRMS = \frac{\sqrt{\Sigma_i \ (V_{computed}(i) - V_{exact}(i))^2}}{max(V_{exact}(i)) \times N_{exact>0}}.$$

Here, $V_{computed}(i)$ is the value computed by the algorithm at the ith pixel, and $V_{exact}(i)$ is the exact analytical solution evaluated at the center of the pixel. $N_{exact>0}$ refers to the number of pixels where the exact analytical solution is greater than zero.

For each subtest, the maximum normalized RMS error over all runs in the subtest is determined. This value must be less than the specified value.

4. Specific Tests to be Carried Out

4.1 Specific Configurations of Interest

Tests 1-7 evaluate scenes of specific interest, for a variety of tilt angles.

Test 1 The object is a sphere of radius 1.00cm, centered at the origin. The input grid is 500x500 pixels with a bounding box of -1.25cm < x < 1.25cm, -1.25cm < y < 1.25cm (50µm pixel size). The output grid is 500x500 pixels with a bounding box of   -2.50cm < x < 2.50cm, -2.50cm < y < 2.50cm (100µm pixel size). The source-object distance is 10cm and the object-detector distance is 2cm. Each subtest covers a range of angles. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
1-1	-80	5.0	-45	0.25%
1-2	-40	0.5	-3.5	0.31%
1-3	-3	0.1	3	0.26%
1-4	3.5	0.5	40	0.31%
1-5	45	5.0	80	0.25%

Test 2 The object is a sphere of radius 2.0cm, centered at the origin. The input grid is 500x500 pixels with a bounding box of -2.5cm < x < 2.5cm, -2.5cm < y < 2.5cm (100µm pixel size). The output grid is 500x500 pixels with a bounding box of -6.0cm < x < 6.0cm, -6.0cm < y < 6.0cm (240µm pixel size). The source-object distance and object-detector distance are both 100cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
2-1	-80	5.0	-45	0.23%
2-2	-40	0.5	-3.5	0.28%
2-3	-3	0.1	3	0.40%
2-4	3.5	0.5	40	0.28%
2-5	45	5.0	80	0.23%

Test 3 The test is the same as Test 2, except that the object is a cylinder of cross sectional radius 2cm and height 4cm, centered at the origin. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
3-1	-80	5.0	-45	0.30%
3-2	-40	0.5	-3.5	0.18%
3-3	-3	0.1	3	1.55%
3-4	3.5	0.5	40	0.18%
3-5	45	5.0	80	0.30%

Test 4 The object is a sphere of radius 2.0cm, centered at the origin. The input grid is 500x500 pixels with a bounding box of -2.5cm < x < 2.5cm, -2.5cm < y < 2.5cm (100µm pixel size). The output grid is 500x500 pixels with a bounding box of -4.0cm < x < 4.0cm, -4.0cm < y < 4.0cm (160µm pixel size). The source-object distance is 400cm and the object-detector distance is 40cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
4-1	-80	5.0	-45	0.23%
4-2	-40	0.5	-3.5	0.28%
4-3	-3	0.1	3	0.37%
4-4	3.5	0.5	40	0.28%
4-5	45	5.0	80	0.23%

Test 5 The object in this test is a cylinder with the same dimensions as Test 3. The input grid is 500x500 pixels with a bounding box of -2.5cm < x < 2.5cm, -2.5cm < y < 2.5cm (100µm pixel size). The output grid is 500x500 pixels with a bounding box of -6.0cm < x < 6.0cm, -6.0cm < y < 6.0cm (240µm pixel size). The source-object distance is 150cm, and the object-detector distance is 67cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
5-1	-80	5.0	-45	0.36%
5-2	-40	0.5	-3.5	0.17%
5-3	-3	0.1	3	2.35%
5-4	3.5	0.5	40	0.17%
5-5	45	5.0	80	0.36%

Test 6 The object is a sphere of radius 2.0cm, centered at the origin. The input grid is 500x500 pixels with a bounding box of -2.5cm < x < 2.5cm, -2.5cm < y < 2.5cm (100µm pixel size). The output grid is 500x500 pixels with a bounding box of -2.5cm < x < 2.5cm, -2.5cm < y < 2.5cm (100µm pixel size). The source-object

distance is 133cm and the object-detector distance is zero. The range of angles and the maximum allowable normalized RMS errors are as follows (note that the angle step is 0.5 for large tilt angles, instead of the usual 5.0).

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
6-1	-80	0.5	-45	0.24%
6-2	-40	0.5	-3.5	0.27%
6-3	-3	0.1	3	0.38%
6-4	3.5	0.5	40	0.27%
6-5	45	0.5	80	0.24%

Test 7 The object is a cylinder with the same dimensions as in Tests 3 and 5. The input grid is 500x500 pixels with a bounding box of -2.5cm < x < 2.5cm, -2.5cm < y < 2.5cm (100μm pixel size). The output grid is 500x500 pixels with a bounding box of -2.5cm < x < 2.5cm, -2.5cm < y < 2.5cm (100μm pixel size). The source-object distance is 133cm and the object-detector distance is zero. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
7-1	-80	5.0	-45	0.41%
7-2	-40	0.5	-3.5	0.21%
7-3	-3	0.1	3	1.27%
7-4	3.5	0.5	40	0.21%
7-5	45	5.0	80	0.41%

4.2 Sphere tests with varying first conjugate

Tests 8-17 evaluate computations of a sphere at a variety of tilt angles. Each test uses a different set of conjugates. The source-object distance ranges from 50cm for Test 8 to 500cm for Test 17 in increments of 50cm. The object-detector distance is always 1/10 of the source-object distance, giving magnification M = 1.1.

Test 8 The object is a sphere with radius 2.0cm, centered at the origin. The input grid is 500x500 pixels with a bounding box of -2.5cm < x < 2.5cm, -2.5cm < y < 2.5cm (100μm pixel size). The output grid is 800x800 pixels with a bounding box of -4.0cm < x < 4.0cm, -4.0cm < y < 4.0cm (100μm pixel size). The source-object distance is 50cm and the object-detector distance is 5cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
8-1	-80	5.0	-45	0.22%
8-2	-40	0.5	-3.5	0.31%
8-3	-3	0.1	3	0.26%
8-4	3.5	0.5	40	0.31%
8-5	45	5.0	80	0.22%

Test 9 The test is the same as Test 8, except the source-object distance is 100cm and the object-detector distance is 10cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
9-1	-80	5.0	-45	0.23%
9-2	-40	0.5	-3.5	0.28%
9-3	-3	0.1	3	0.40%
9-4	3.5	0.5	40	0.28%
9-5	45	5.0	80	0.23%

Test 10 The test is the same as Test 8, except the source-object distance is 150cm and the object-detector distance is 15cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
10-1	-80	5.0	-45	0.23%
10-2	-40	0.5	-3.5	0.27%
10-3	-3	0.1	3	0.37%
10-4	3.5	0.5	40	0.27%
10-5	45	5.0	80	0.23%

Test 11 The test is the same as Test 8, except the source-object distance is 200cm and the object-detector distance is 20cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
11-1	-80	5.0	-45	0.23%
11-2	-40	0.5	-3.5	0.27%
11-3	-3	0.1	3	0.37%
11-4	3.5	0.5	40	0.27%
11-5	45	5.0	80	0.23%

Test 12 The test is the same as Test 8, except the source-object distance is 250cm and the object-detector distance is 25cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
12-1	-80	5.0	-45	0.23%
12-2	-40	0.5	-3.5	0.27%
12-3	-3	0.1	3	0.33%
12-4	3.5	0.5	40	0.27%
12-5	45	5.0	80	0.23%

Test 13 The test is the same as Test 8, except the source-object distance is 300cm and the object-detector distance is 30cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
13-1	-80	5.0	-45	0.24%
13-2	-40	0.5	-3.5	0.27%
13-3	-3	0.1	3	0.33%
13-4	3.5	0.5	40	0.27%
13-5	45	5.0	80	0.24%

Test 14 The test is the same as Test 8, except the source-object distance is 350cm and the object-detector distance is 35cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
14-1	-80	5.0	-45	0.24%
14-2	-40	0.5	-3.5	0.27%
14-3	-3	0.1	3	0.33%
14-4	3.5	0.5	40	0.27%
14-5	45	5.0	80	0.24%

Test 15 The test is the same as Test 8, except the source-object distance is 400cm and the object-detector distance is 40cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
15-1	-80	5.0	-45	0.25%
15-2	-40	0.5	-3.5	0.27%
15-3	-3	0.1	3	0.36%
15-4	3.5	0.5	40	0.27%
15-5	45	5.0	80	0.25%

Test 16 The test is the same as Test 8, except the source-object distance is 450cm and the object-detector distance is 45cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
16-1	-80	5.0	-45	0.25%
16-2	-40	0.5	-3.5	0.27%
16-3	-3	0.1	3	0.32%
16-4	3.5	0.5	40	0.27%
16-5	45	5.0	80	0.25%

Test 17 The test is the same as Test 8, except the source-object distance is 500cm and the object-detector distance is 50cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
17-1	-80	5.0	-45	0.26%
17-2	-40	0.5	-3.5	0.27%
17-3	-3	0.1	3	0.31%
17-4	3.5	0.5	40	0.27%
17-5	45	5.0	80	0.26%

4.3 Cylinder tests with varying first conjugate

Tests 18-27 evaluate computations of a cylinder at a variety of tilt angles. Each test uses a different set of conjugates. The source-object distance ranges from 50cm for Test 8 to 500cm for Test 17 in increments of 50cm. The object-detector distance is always 1/10 of the source-object distance, giving magnification M = 1.1.

Test 18 The test is the same as Test 8, except the object is a cylinder with the same dimensions as in Test 3. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
18-1	-80	5.0	-45	0.35%
18-2	-40	0.5	-3.5	0.30%
18-3	-3	0.1	3	1.86%
18-4	3.5	0.5	40	0.30%
18-5	45	5.0	80	0.35%

Test 19 The test is the same as Test 18, except the source-object distance is 100cm and the object-detector distance is 10cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
19-1	-80	5.0	-45	0.29%
19-2	-40	0.5	-3.5	0.20%
19-3	-3	0.1	3	1.49%
19-4	3.5	0.5	40	0.20%
19-5	45	5.0	80	0.29%

Test 20 The test is the same as Test 18, except the source-object distance is 150cm and the object-detector distance is 15cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
20-1	-80	5.0	-45	0.37%
20-2	-40	0.5	-3.5	0.19%
20-3	-3	0.1	3	1.40%
20-4	3.5	0.5	40	0.19%
20-5	45	5.0	80	0.37%

Test 21 The test is the same as Test 18, except the source-object distance is 200cm and the object-detector distance is 20cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
21-1	-80	5.0	-45	0.30%
21-2	-40	0.5	-3.5	0.18%
21-3	-3	0.1	3	1.53%
21-4	3.5	0.5	40	0.18%
21-5	45	5.0	80	0.30%

Test 22 The test is the same as Test 18, except the source-object distance is 250cm and the object-detector distance is 25cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
22-1	-80	5.0	-45	0.33%
22-2	-40	0.5	-3.5	0.18%
22-3	-3	0.1	3	1.36%
22-4	3.5	0.5	40	0.18%
22-5	45	5.0	80	0.33%

Test 23 The test is the same as Test 18, except the source-object distance is 300cm and the object-detector distance is 30cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
23-1	-80	5.0	-45	0.37%
23-2	-40	0.5	-3.5	0.18%
23-3	-3	0.1	3	1.37%
23-4	3.5	0.5	40	0.18%
23-5	45	5.0	80	0.37%

Test 24 The test is the same as Test 18, except the source-object distance is 350cm and the object-detector distance is 35cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
24-1	-80	5.0	-45	0.39%
24-2	-40	0.5	-3.5	0.18%
24-3	-3	0.1	3	1.52%
24-4	3.5	0.5	40	0.18%
24-5	45	5.0	80	0.39%

Test 25 The test is the same as Test 18, except the source-object distance is 400cm and the object-detector distance is 40cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
25-1	-80	5.0	-45	0.41%
25-2	-40	0.5	-3.5	0.17%
25-3	-3	0.1	3	1.76%
25-4	3.5	0.5	40	0.17%
25-5	45	5.0	80	0.41%

Test 26 The test is the same as Test 18, except the source-object distance is 450cm and the object-detector distance is 45cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
26-1	-80	5.0	-45	0.42%
26-2	-40	0.5	-3.5	0.18%
26-3	-3	0.1	3	1.69%
26-4	3.5	0.5	40	0.18%
26-5	45	5.0	80	0.42%

Test 27 The test is the same as Test 18, except the source-object distance is 500cm and the object-detector distance is 50cm. The range of angles and the maximum allowable normalized RMS errors are as follows.

Test Number	Start Angle	Angle Step	End Angle	Max Error Allowed
27-1	-80	5.0	-45	0.43%
27-2	-40	0.5	-3.5	0.17%
27-3	-3	0.1	3	1.44%
27-4	3.5	0.5	40	0.17%
27-5	45	5.0	80	0.43%

4.4 Testing a cylinder for a wide range of resolutions.

Test 28 The object is a cylinder with the same dimensions as in Tests 3 and 5. The source-object distance is 133cm and the object-detector distance is zero. The tilt angle is 8 degrees. The input and output grids each have a bounding box of -2.5cm < x < 2.5cm, -2.5cm < y < 2.5cm. The resolutions and pixel size, and the allowable normalized RMS errors are as follows.

Test Number	Input Grid Resolution	Input Grid Pixel Size (μm)	Output Grid Resolution	Output Grid Pixel Size (μm)	Max Error Allowed
28-1	125	400	125	400	2.71%
28-2	250	200	250	200	0.30%
28-3	500	100	500	100	0.15%
28-4	1000	50	1000	50	0.08%
28-5	1500	33	1500	33	0.06%
28-6	2000	25	2000	25	0.06%

Final Acceptance Criteria

If all the above tests are passed the glyph will be considered acceptable for release. If any tests are failed, a decision will be made as to whether the deficiency will need to be corrected and the test repeated.

5. References

1. PLAN-SQM-BIE-104, *Bayes Inference Engine*.